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SLOPE PARAMETER FOR THE DIFFERENTIAL CROSS-SECTION FOR THE REACTION $p + d \to X + d$ IN THE REGION OF SMALL MOMENTUM TRANSFER AT FERMILAB ENERGIES*

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Abstract

We have used a deuterium gas jet target in the circulating beam of the Fermilab accelerator to study the M_x^2 and s dependence and the slope parameter for $pd \to Xd$ in the region $0.025 \leq |t| \leq 0.17$ $(GeV/c)^2$ and $5 \leq M_x^2 \leq 0.068s$ GeV^2. A simple parametrization in terms of the variable $(1 - x)$ is found.

We report the results of an investigation of the s and M_x^2 dependence of the slope parameter for the inclusive reaction:

$$p + d \to X + d \tag{1}$$

in the region $0.025 < |t| < 0.17$ $(GeV/c)^2$ and $5 \leq M_x^2 \leq 0.068s$ GeV^2. Measurements were performed at four laboratory beam momenta: 65, 153, 273, and 372 GeV/c.

The investigation of process (1) has been done in the internal beam of the Fermilab accelerator using a gas jet target. Recoiling deuterons were detected by means of telescopes of semiconductor detectors in the angular range 4-35^o with respect to the plane perpendicular to the incident beam. The details of the method and the results for the differential cross-section for reaction (1) and comparison with $p + p \to X + p$ interactions have been published.[1] In that paper, it was shown that in the region of high M_x^2 the Feynman scaling variable, x, is useful for parametrizing the cross-section.

$$\frac{M_x^2 - M_p^2}{s} \simeq (1 - x) \simeq \frac{|t|^{1/2}}{M_R} \left[\sin\theta - \frac{p_o + M_R}{p_o} \cdot \frac{|t|^{1/2}}{2\,M_R}\right] \tag{2}$$

where M_R is the mass of the deuteron, p_o the momentum of the incoming proton, and $s \simeq 2\,M_R p_o$.

Since the publication of Ref. 1, we have continued the data analysis and increased the statistical accuracy of the 65 and 372 GeV/c data by a factor of 2 and added one more beam momentum, 273 GeV/c. Combining these enables us to extract information about the slope parameter by fitting it with the form:

$$\frac{d^2\sigma}{dx\,dt} = a(x,s,t_o)\ \exp\left[b(x,s,)(t-t_o) + c(t^2-t_o{}^2)\right] \quad . \tag{3}$$

The parameter c is fixed at the value of 62.3 $(\mathrm{GeV/c})^{-4}$ found in Ref. 2. The value of t_o was chosen = -.05 $(\mathrm{GeV/c})^2$ to suppress the correlation between parameters. The value of the b-parameter is listed in Table I and displayed in Fig. 1 as a function of $M_x{}^2$ for the four incident momenta in the range $5 \leq M_x{}^2 \leq 96$ GeV^2. We present on the same figure the values of b from Ref. 2 (some points of Ref. 2, with $\Delta b > 2.0$ have been omitted for clarity). The data from Ref. 2 are systematically lower than the new data, however, the s and $M_x{}^2$ dependences are similar.

In Fig. 2 the same data are presented as a function of (1 - x). As can be seen in the figure, the b-parameter is independent of energy within the errors. To check this conclusion in a quantitative fashion, we fit the data in the form:

$$b(x,s) = b_o + \alpha_1 \ln s + \alpha_2 \ln (1 - x) \tag{4}$$

The results of the fit are $b_o = 26.50 \pm 0.69$, $\alpha_1 = 0.19 \pm 0.10$, $\alpha_2 = -1.76 \pm 0.11$ with $\chi^2/DF = 153/69$. The non zero value of α_1 indicates a possible small deviation from scaling. Setting $\alpha_1 = 0$ changes the other parameters only slightly: $b_o = 27.56 \pm 0.40$, $\alpha_2 = -1.31 \pm 0.11$, $\chi^2/DF = 157/70$. In Fig. 2 the line represents the calculation of (4) with $\alpha_1 = 0$.

Using (2) we can rewrite formula (4) in the following way:

$$b(x,s) = b(M_x^2,s) = b_o + (\alpha_1 - \alpha_2)\ln s + \alpha_2 \ln M_x^2 \qquad (5)$$

where $\alpha_1 - \alpha_2 = 1.95 \pm 0.21$. The calculation using formula (5) is represented in Fig. (1) by the solid lines.

Parametrization of the differential cross-sections in the form

$$\frac{d^2\sigma}{dx\,dt} = a(x,s)e^{b_o t + ct^2} s^{\alpha_1 t} (1 - x)^{\alpha_2 t} \qquad (6)$$

and parameter values can be qualitatively understood in the framework of the Regge pole theory. In the region of large M_x^2, $M_x^2 >> m^2$, the inclusive cross-section is expected to be described by the triple Regge formula[4]

$$\frac{d^2\sigma}{dx\,dt} = \sum_{ijk} G_{ijk}(t)(1-x)^{\alpha_k(0) - \alpha_i(t) - \alpha_j(t)} s^{\alpha_k(0)-1} \qquad (7)$$

where the $G_{i,j,k}$'s are effective values of contributions of the triple Regge couplings and $\alpha_i(t) = \alpha_P(t) = \alpha_P(0) + \gamma t$, $\alpha_i(t) = \alpha_R(t) = \alpha_R(0) + \beta t$ are Pomeron and Regge trajectories, respectively. Note that in the triple Regge description there is no energy dependence for b-parameter. Comparison of (6) and (7) leads to $\alpha_1 = 0$, and α_2 has a meaning of the sum of the slopes of i- and j-trajectories in the triple Regge diagram.

Considering (1 - x) dependence of b-parameter, there are three groups of all possible triple Regge contributions in pd inelastic interactions

PPP, PPR	$-\alpha_2 = 2\gamma$	
PRP, RPP, PRR, RPR	$-\alpha_2 = \gamma + \beta$	(7)
RRP, RRR	$-\alpha_2 = 2\beta$	

The standard parametrization of trajectories is $\alpha_P(t) = 1.06 + 0.28t$, $\alpha_R(t) = 0.5 + t$, so $2\gamma = 0.56$, $\gamma + \beta = 1.28$ and $2\beta = 2$, therefore the value of $-\alpha_2$ can vary from 0.56 to 2. The triple Regge analysis of inelastic pp interactions[5] at $s = 700$ GeV^2 shows that in the region of $(1 - x) < 0.02$ there is predominance of contributions of PPR or PPP exchanges, similarly PRP and RRP predominate in the regions $0.02 \leq (1-x) \leq 0.04$ and $(1-x) > 0.04$, respectively.

In our analysis the value of b-parameter has been mainly obtained at large $1 - x$ and $\alpha_2 = -1.76$ qualitatively confirms prevalence of RRP exchange contribution in this region.

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Table I

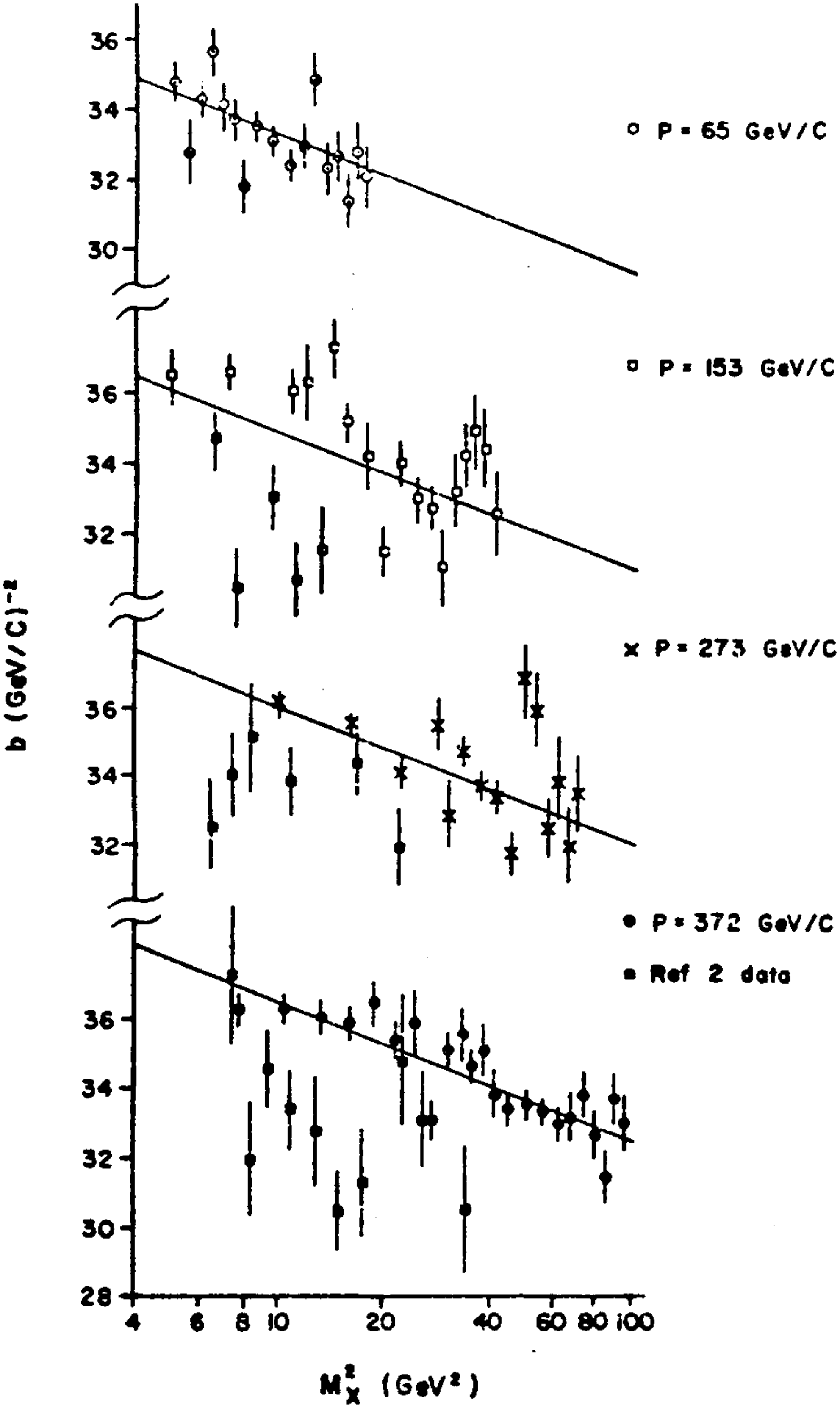
1 - x	p = 65 GeV/c M_x^2 GeV^2	b $(GeV/c)^{-2}$	p = 153 GeV/c M_x^2 GeV^2	b $(GeV/c)^{-2}$	p = 273 GeV/c M_x^2 GeV^2	b $(GeV/c)^{-2}$	p = 372 GeV/c M_x^2 GeV^2	b $(GeV/c)^{-2}$
.005							7.9	36.3 ± 0.4
.007			4.9	36.5 ± 0.7			10.7	36.3 ± 0.4
.009					10.1	36.1 ± 0.4	13.5	36.1 ± 0.4
.011			7.2	36.6 ± 0.4			16.3	35.9 ± 0.4
.013							19.1	36.5 ± 0.6
.015					16.3	35.6 ± 0.5	21.9	35.4 ± 0.5
.017	5.1	34.8 ± 0.5	10.7	36.0 ± 0.6			24.7	35.9 ± 0.9
.019	5.6	32.8 ± 0.9	11.9	36.2 ± 1.1			27.5	33.1 ± 0.5
.021	6.1	34.3 ± 0.4			22.5	34.0 ± 0.5	30.3	35.1 ± 0.5
.023	6.6	35.6 ± 0.6	14.2	37.2 ± 0.8			33.1	35.5 ± 0.8
.025	7.1	34.1 ± 0.6	15.4	35.1 ± 0.5			35.9	34.7 ± 0.5
.027	7.6	33.7 ± 0.6			28.7	35.4 ± 0.8	38.7	35.1 ± 0.8
.029	8.1	31.8 ± 0.8	17.7	34.1 ± 1.0	30.7	32.8 ± 1.0	41.5	33.9 ± 0.7
.032	8.8	33.5 ± 0.4	19.4	31.4 ± 0.7	33.8	34.6 ± 0.5	45.7	33.4 ± 0.5
.036	9.8	33.1 ± 0.4	21.7	33.9 ± 0.6	37.9	33.5 ± 0.4	51.3	33.5 ± 0.4
.040	10.8	32.4 ± 0.4	24.0	32.9 ± 0.6	42.0	33.3 ± 0.5	56.9	33.3 ± 0.4
.044	11.8	32.9 ± 0.6	26.3	32.6 ± 0.6	46.2	31.7 ± 0.6	62.5	33.0 ± 0.5
.048	12.8	34.8 ± 0.8	28.6	30.9 ± 1.1	50.3	36.7 ± 1.0	68.1	33.2 ± 0.7
.052	13.8	32.3 ± 0.7	31.0	33.1 ± 1.1	54.4	35.8 ± 1.0	73.7	33.8 ± 0.7
.056	14.8	32.6 ± 0.7	33.3	34.1 ± 0.9	58.5	32.4 ± 0.8	79.3	32.7 ± 0.7
.060	15.8	31.3 ± 0.8	35.6	34.8 ± 1.1	62.6	33.7 ± 1.3	84.9	31.5 ± 0.7
.064	16.8	32.7 ± 0.8	37.9	34.3 ± 1.1	66.7	31.9 ± 1.1	90.5	33.7 ± 0.8
.068	17.8	32.0 ± 0.9	40.2	32.4 ± 1.2	70.8	33.4 ± 1.1	96.1	33. ± 0.8

Table 1. The values of b-parameter are given as a function of M_x^2 for the four incident proton momenta of 65, 153, 273 and 372 GeV/c in the range $5 \le M_x^2 \le 96$ GeV^2.

Figure Captions

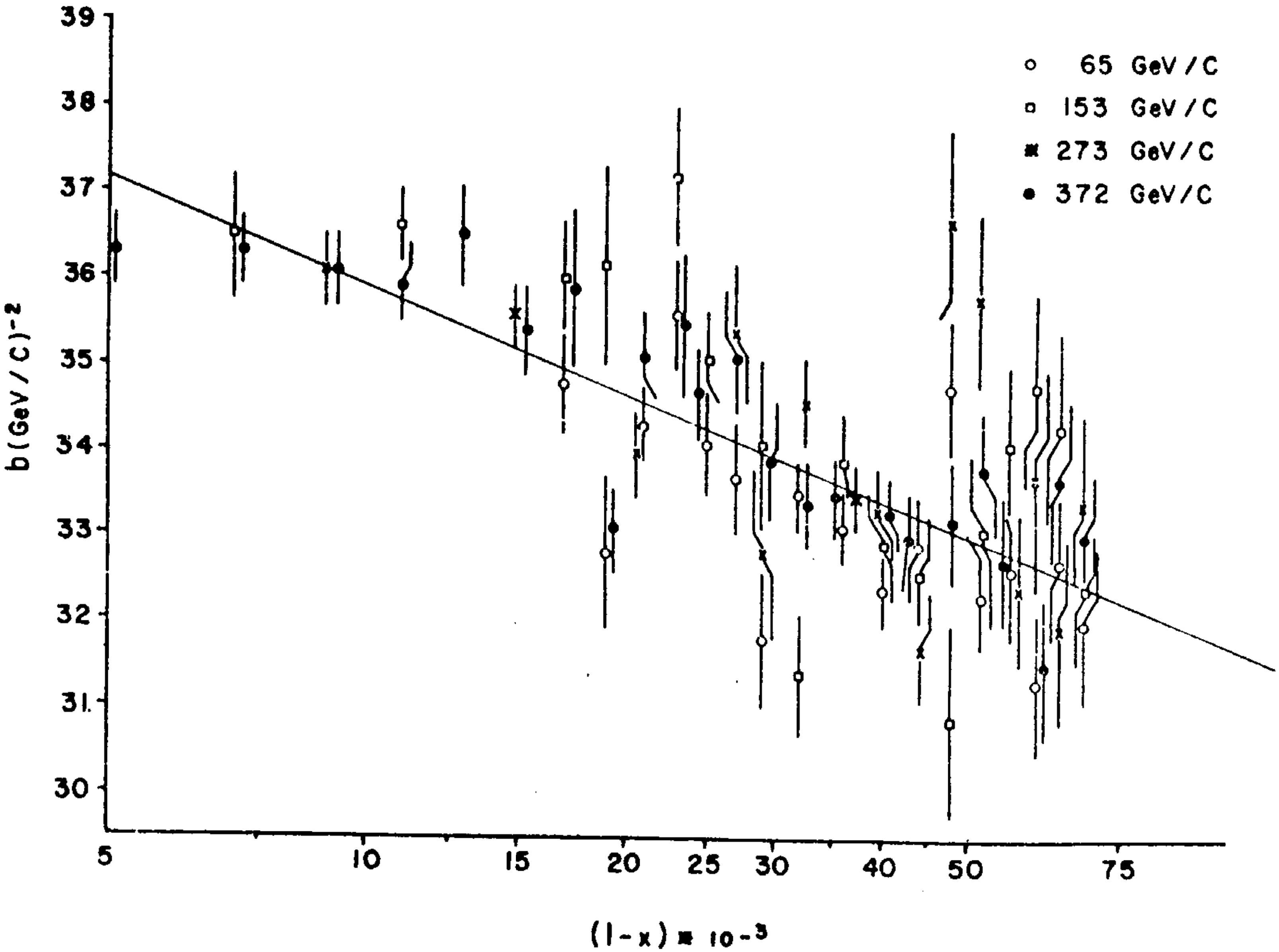
Figure 1. The b-parameters are shown as a function of M_x^2 for four incident proton momenta of 65, 153, 273 and 372 GeV/c in the range $5 \leq M_x^2 < 96$ GeV^2. The fitted lines are given by the equation (5) in the text. Data points from Ref. 2 are also shown for three incident proton momenta of 153, 273 and 372 GeV/c.

Figure 2. The b-parameters for all four momenta of this experiment are shown as a function of $1 - x$. The fitted line is calculated from equation (4) in the text, where $\alpha_1 = 0.0$ and $\alpha_2 = -1.81$.



36
34
32
30
○ P = 65 GeV/C
□ P = 153 GeV/C
× P = 273 GeV/C
● P = 372 GeV/C
■ Ref 2 data
b (GeV/C)⁻²
28
4
6
8
10
20
40
60
80
100
M²x (GeV²)

Fig. 1



65 GeV / C
153 GeV / C
273 GeV / C
372 GeV / C
b (GeV / C)-2
39
38
37
36
35
34
33
32
31
30
5
10
15
20
25
30
40
50
75
(1-x) * 10-3

Fig. 2